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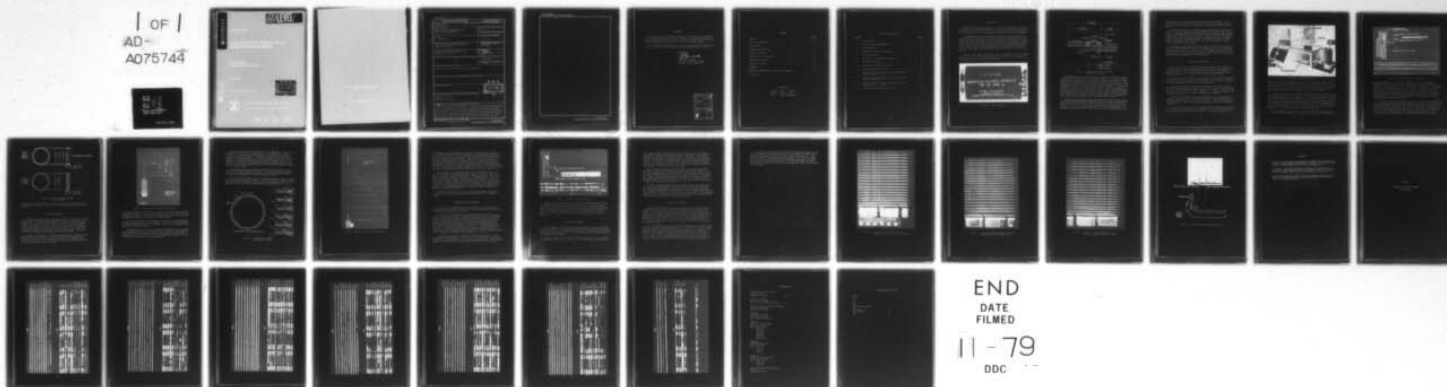
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JUL 79 C W ANDERSON
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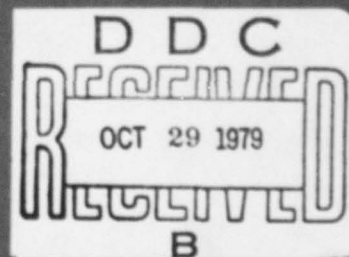
NSWC TR 79-266

ULTRASONIC C-SCAN TESTING OF MK 38 MISSILE WARHEAD WELDMENTS

by
C. W. ANDERSON
Weapons Systems Department

JULY 1979

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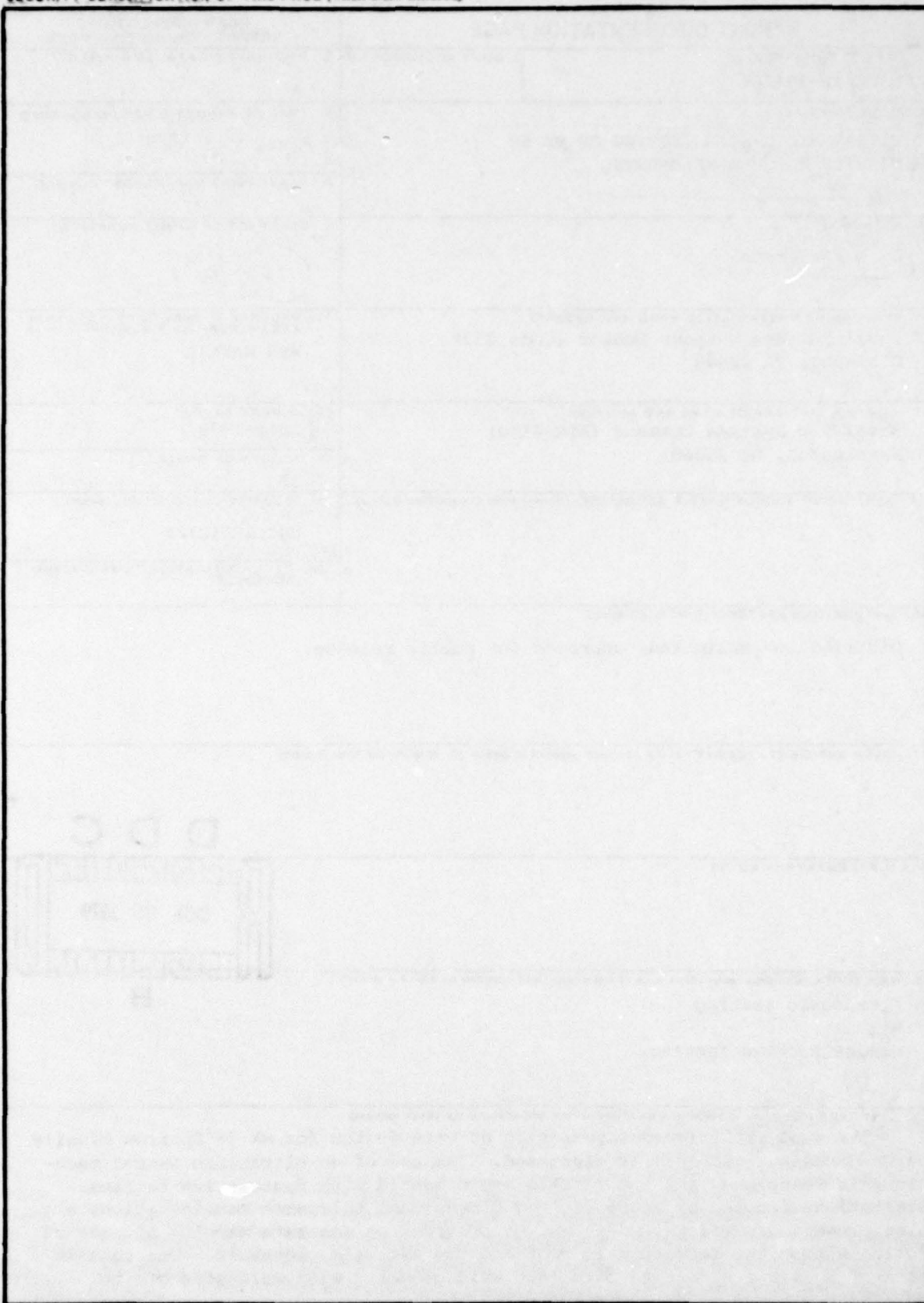
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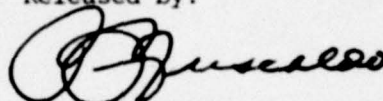
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FOREWORD

This report documents an effort conducted by the Materials Science Branch of the Survivability and Applied Science Division for the Warheads Branch of the Gun Systems and Munitions Division. The task reported is part of the Mk 38 Warhead Weld Defect program funded by the Naval Air Systems Command.

This report was reviewed by Mr. J. D. Hall, Head, Materials Science Branch, and Mr. D. S. Malyevac, Head, Survivability and Applied Science Division.

Released by:



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Assistant for Weapons Systems
Weapons Systems Department

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SI CONVERSION

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INTRODUCTION

The Mk 38 Sparrow missile warhead is a continuous rod warhead. Instead of shattering into separate fragments at detonation, the warhead casing unfolds and expands into a large continuous ring of welded steel rods. The object is to cut the target in half, as opposed to puncturing it with discrete fragments.

The warhead functioning requirements of the Mk 38 are compounded, since the warhead is also utilized as a structural member of the missile body. The warhead is located approximately at the center of the Sparrow missile, connecting the forward and aft missile sections. The missile is suspended beneath an aircraft wing near the missile's center of gravity. This is also the location of the warhead. Thus, the warhead is subject to large bending moments during launch, captive flight, and hard landings of the host aircraft. If the warhead fails, the missile will break in half and could result in the loss of an aircraft.

Figures 1 and 2 depict the Mk 38 warhead. Note the welds near the forward and aft ends. These welds fasten the continuous rod bundle, as well as a thin sheet metal skin, to the threaded forward and aft end rings. The quality of these welds determines the warhead's strength.

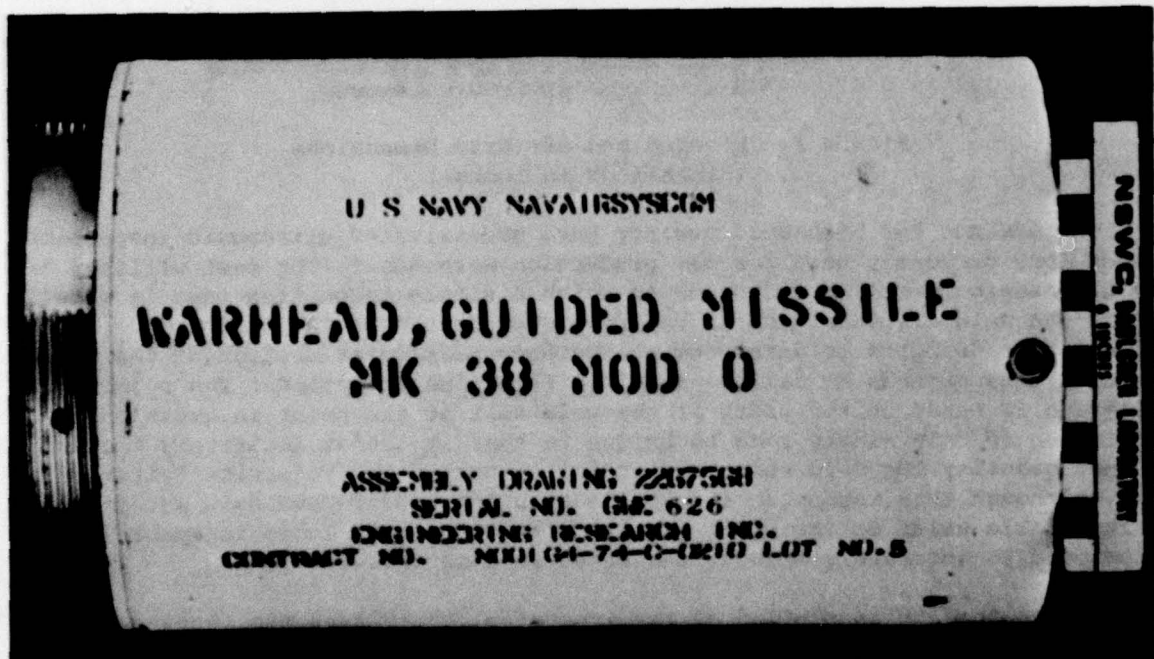


Figure 1. Mk 38 Warhead

technique was highly dependent upon operator skill and motivation. Thus, results were not necessarily reproducible. This led to a situation of uncertainty concerning warheads that had previously been tested using the contact method.

To estimate the condition of Fleet warheads that had previously been inspected, it became necessary to determine the contact method's limits of reliability. Such a variability study was performed by the Weapons Quality Engineering Center (WQEC), Concord, California.³ The Concord study confirmed the suspicion that the contact method can give irreproducible results. Simultaneously, the Naval Surface Weapons Center was tasked to study the relation between weld geometry and weld strength. The study used destructive bend testing to determine weld strength.

In conjunction with the destructive testing, a technique was needed to accurately measure weld condition prior to mechanical loading. An ultrasonic C-scan test was developed to ensure that a full spectrum of weld conditions was mechanically tested, as well as to provide an accurate record of the weld condition prior to the destructive mechanical loading. This report concerns the development and evaluation of this technique.

FORWARD WELD INSPECTION

The principal area of concern with the forward weld is the root area. This region has the highest stresses because of the narrow root geometry and the machining away of the forward sidewall weld during the manufacturing process (Figure 2). In addition, experience with this particular weld has shown that lack of fusion is most likely to occur at the weld root.

The ultrasonic C-scan technique was chosen as the most promising means of nondestructively characterizing weld root geometry. When used in conjunction with a finely focused transducer, the C-scan technique was able to accurately map fused and nonfused regions of the forward weld root.

The C-scan equipment consisted of an Automation Industries 450 Series Laboratory Scanner, a Tektran Immerscope II with PR-17 and FG-10 receiver and gate, the Tektran RIA-10ATS recorder interface, an Automation Industries US717 manipulator, and a Harrisonic .250-in.-diameter, 1-in. focused transducer with a 10-MHz output frequency. Figure 3 shows the basic apparatus.

The 450 Series Laboratory Scanner was equipped with a turntable and a motorized vertical drive to allow the warhead to be rotated while slowly incrementing the transducer in the vertical direction. Signals were recorded on a rotary drum by an electric pen whose motion matched that of the inspection transducer.

Figure 4 reveals the presence of a nonfused interface adjacent and parallel to the weld root interface. The proximity of this nonfused interface to the forward weld shoulder is of prime concern. This area corresponds to the

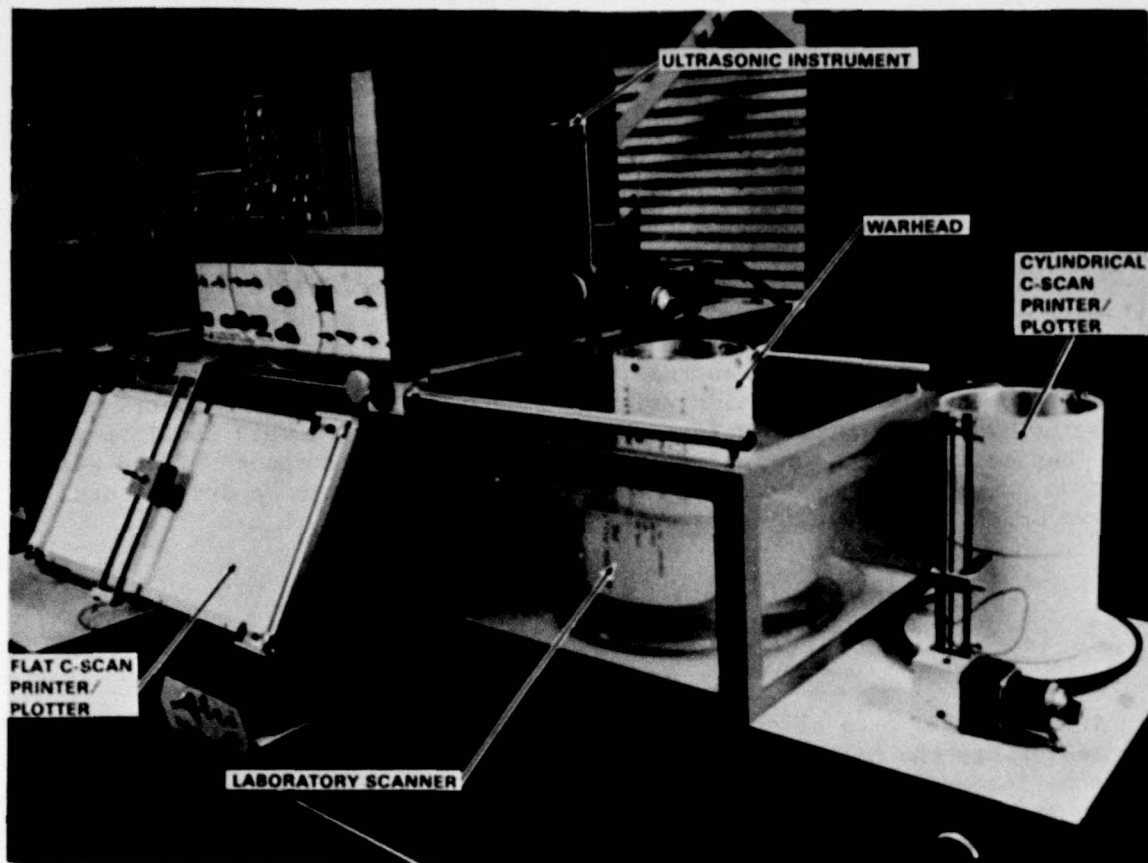


Figure 3. C-Scan Apparatus

smallest cross section of metal holding the warhead together. Thus, this distance from the nonfused interface to the machined forward weld shoulder is the determining factor in estimating forward weld strength. Typically, it varies from about .100 in. to near zero for the warheads tested to date. A distance of only .050 in. may still be acceptable, so it is necessary to be able to measure the width of soundly fused (welded) metal quite accurately.

Transducer position measured along the warhead axis is extremely critical in measuring the condition of the weld. This position is measured with respect to the machined shoulder of the forward weld. At the start of a scan, the center of the transducer beam is positioned directly over the shoulder. This reference point is marked on the C-scan as a solid line at the bottom of the scan. As the warhead is rotated and the transducer moves aft along the warhead, the nonfused interface, or lack of fusion at the weld root, will appear (Figure 4). Since the scan is made on a one-to-one scale, the distance from the machined shoulder to the nonfused interface can be measured directly.

Accurate positioning of the transducer is accomplished through the use of the forward weld turntable adapter. Figure 5 is a sketch of the adapter.

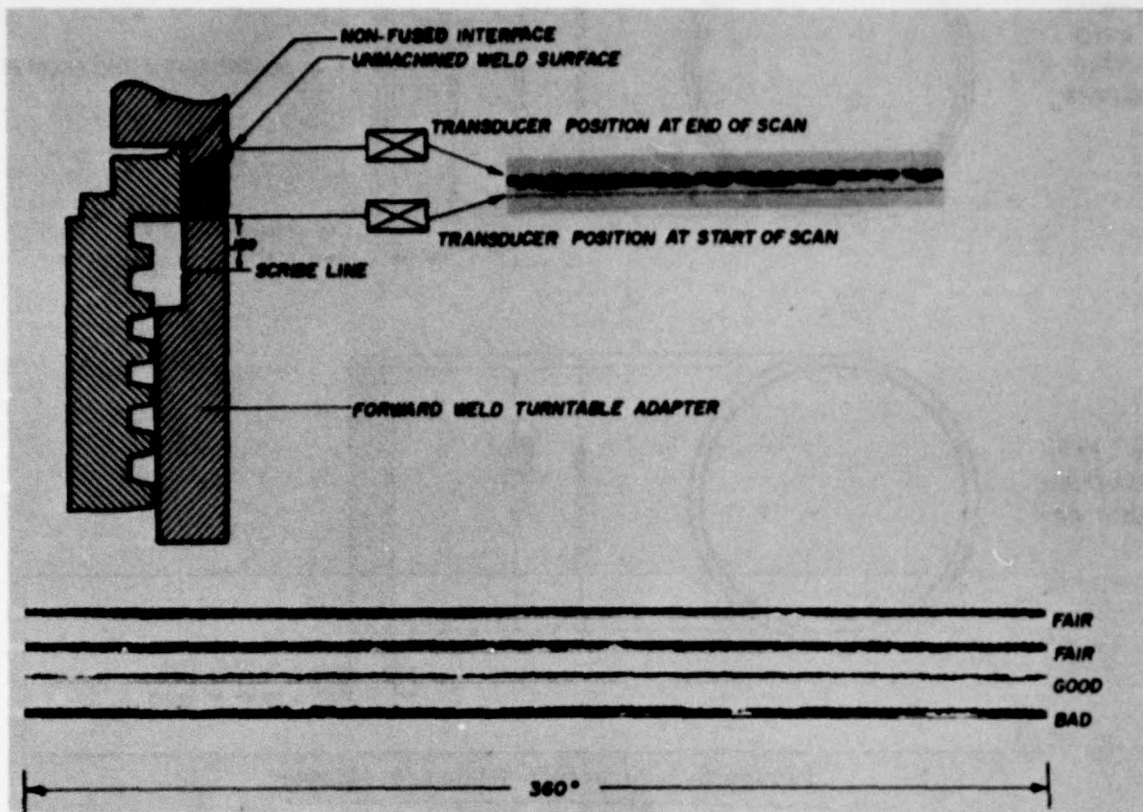
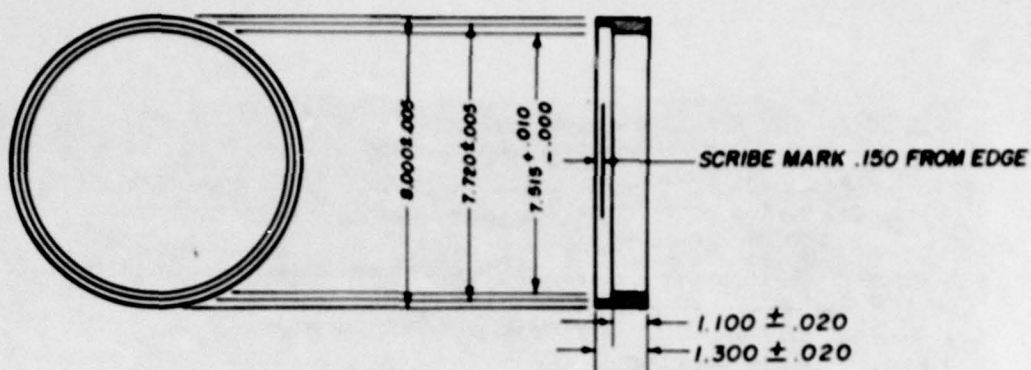


Figure 4. Forward Weld Inspection Technique

Note the scribe line on the inside circumference. When the transducer is positioned directly over this line, the amplitude of the inside diameter reflection passes through a minimum. By raising the transducer .150 in. from this point, one positions the center of the beam at the top edge of the adapter ring. Since the weld shoulder rests on this edge, the position also corresponds to that of the machined shoulder. Repeated calibration using this technique has shown a reproducibility of within $\pm .002$ in. in the positioning of the transducer. Such accuracy is achievable through the use of a finely focused beam .020 in. wide at the focal distance as determined by the -3 dB amplitude points of the beam (Figure 6).

The forward weld turntable adapter is also used to calibrate the position of the flaw gate, as well as the echo amplitude at which the C-scan will record. The minimum thickness of the turntable adapter corresponds to the distance of the weld root beneath the machined weld crown. This enables the adapter to be used to position the flaw gate of the ultrasonic instrument. The reflection from the inside diameter is also used to calibrate the amplitude sensitivity of the scan. With the amplitude of the inside diameter reflection set at 100 percent of the screen height, the C-scan printing threshold is set at

FORWARD
WELD
TURNABLE
ADAPTER



AFT WELD
TURNABLE
ADAPTER

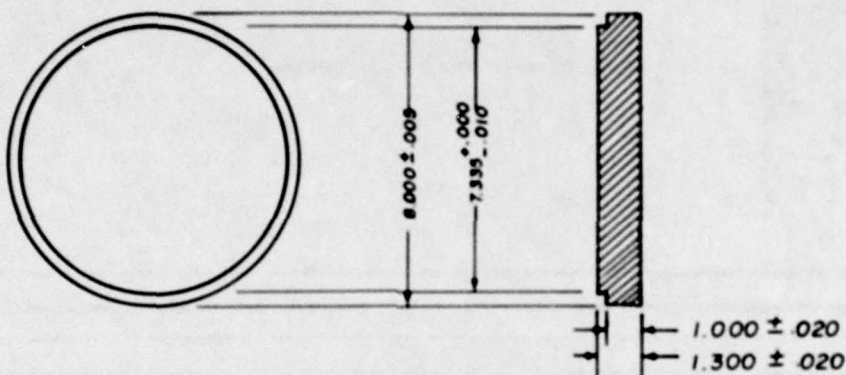


Figure 5. Turntable Adapters (dimensions in inches)

25 percent of the screen height. This setting was determined empirically and is discussed in detail in the Destructive Test Correlation portion of this report.

AFT WELD INSPECTION

The aft weld presents less of a problem in terms of reliability. Figure 2 shows the weld to have two complete sidewalls, making it stronger than the forward weld. The aft weld can tolerate lack of fusion at the root and still depend on the sidewalls to hold it together. For this reason, a sidewall inspection was chosen as being the most indicative of the aft weld strength. A contributing factor in choosing to test the sidewalls was the presence of incompletely machined aft weld crowns on many of the warheads. This rough surface would have made a root inspection unreliable at best.

To inspect the aft weld, it is necessary to generate an ultrasonic beam perpendicular to the sidewalls. This is accomplished by angulating the inspecting transducer to 23.6 deg from the normal to the outside surface of the aft end ring. This creates a shear mode ultrasonic beam within the steel end ring at the required angle of 60 deg.

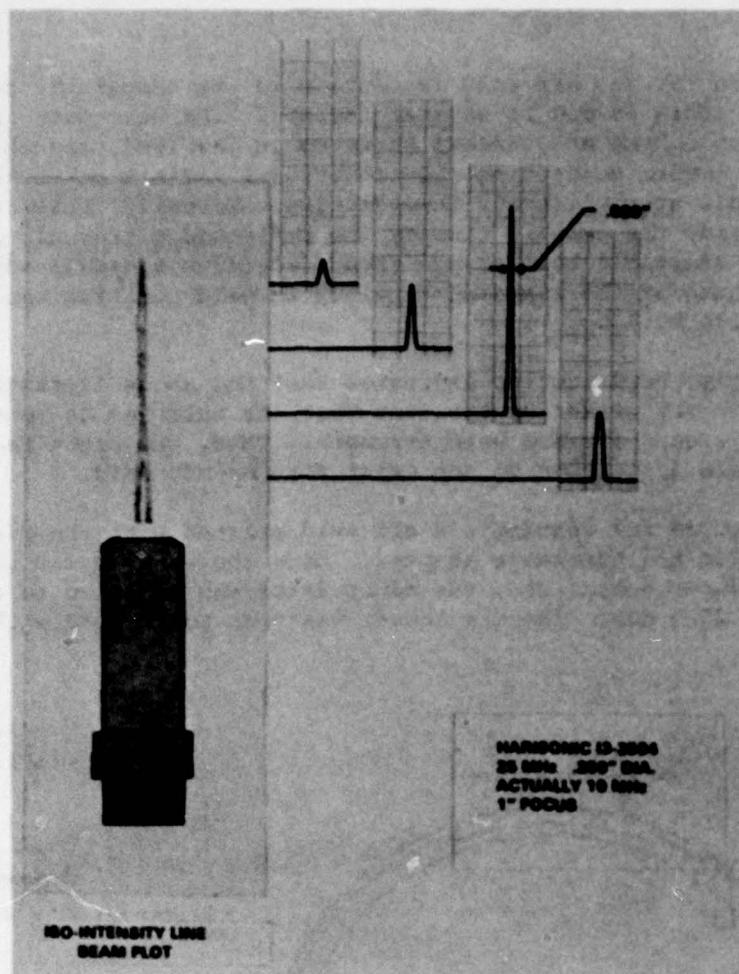


Figure 6. Beam Profile of Forward Weld Transducer

The uncertainty in the position of the aft weld due to a dimensional tolerance buildup requires that the transducer scan in the axial direction while the warhead is rotated. The result is a somewhat distorted C-scan, which can nonetheless be used as an indication of aft weld quality.

To determine how well such a technique might work, a test standard was constructed, machined from an actual warhead. An electric discharge machine was used to remove metal from both sidewalls, creating varying degrees of simulated lack of fusion (Figure 7).

The hardware used for aft weld inspection was identical to that required for the forward weld, with the exception of the transducer and a warhead centering adapter for the turntable. The aft weld inspection transducer was a Panametrics A309 R with a 4-in. focus and a 5-MHz-diameter element. The aft weld transducer beam profile appears in Figure 8.

Resolution for the aft weld inspection is not comparable to that of the forward weld. This is due to several factors. The beam path is longer, reflection from convex and concave surfaces is involved, and the threaded regions cause severe scattering. An additional limitation is that it is not possible to tell which sidewall is defective. Normally, this can be accomplished by noting the transit time of the reflected ultrasonic pulse. This method is not adaptable to distinguishing defective sidewall echoes on the aft weld, because of the large uncertainty in weld position caused by a dimensional tolerance buildup.

Fortunately, bend testing indicates that the above limitations on aft weld inspection are offset by the fact that the weld can be mostly unfused and yet still exceed forward weld strength. Thus, the tight requirements on the forward weld inspection do not exist for the aft weld.

The procedure for testing the aft weld started with the placement of the test standard on the turntable adapter. Once the warhead was properly centered and the transducer normalized, the manipulator was adjusted to create an incident angle of 23.5 deg. The transducer was then positioned with a 2.5-in.

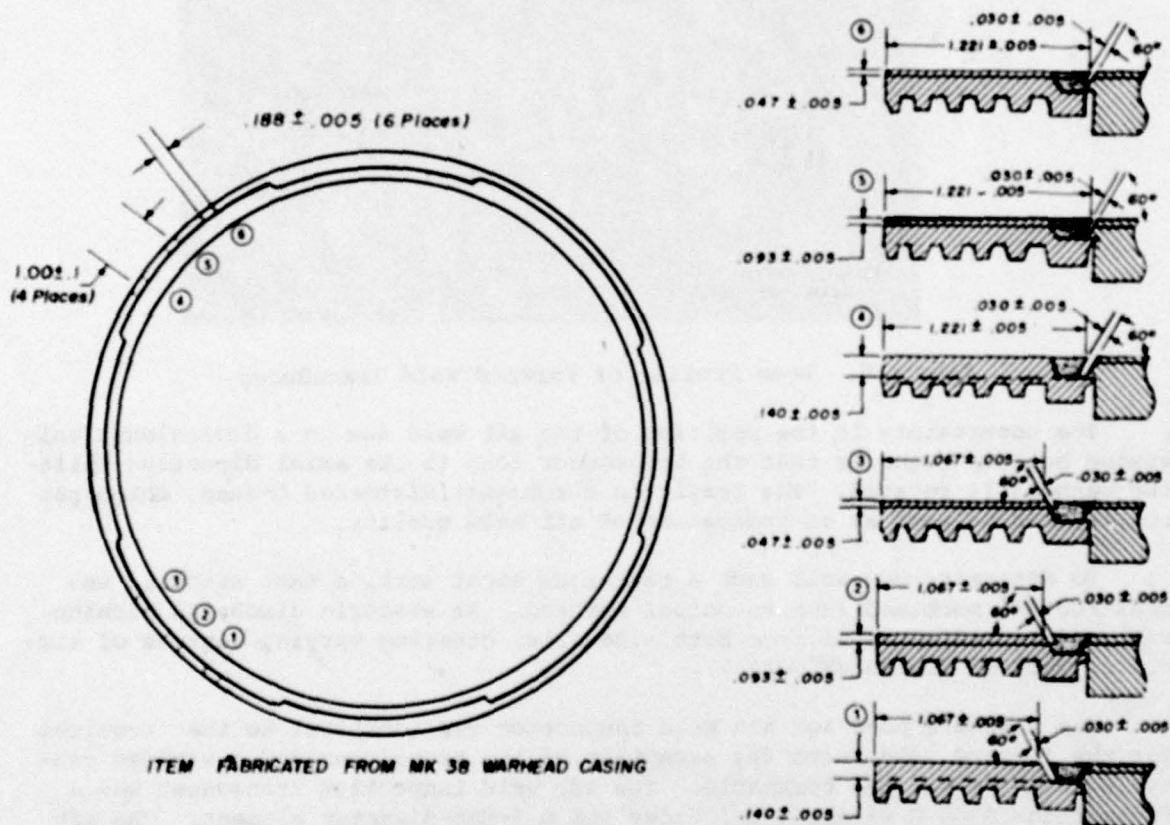


Figure 7. Aft Weld Test Standard
(dimensions in inches)

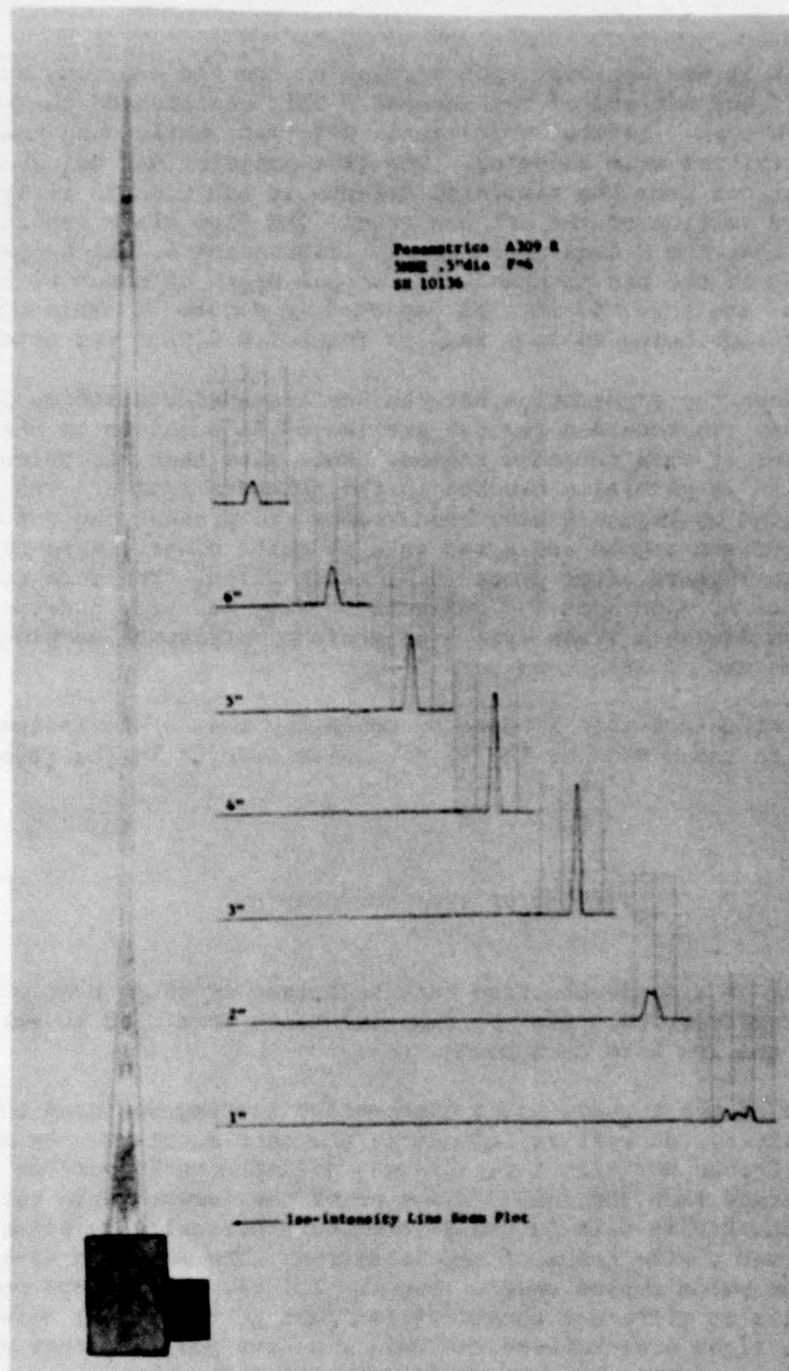


Figure 8. Beam Profile of Aft Weld Transducer

waterpath so that it was incident upon a point on the aft end ring surface .2 in. forward of the aft end of the warhead. This represented the starting position for each scan. Several trial scans were made while gate positioning and alarm sensitivities were adjusted. The gate position was adjusted to include all indications from the simulated defects in addition to reflections from the threaded portion of the aft end ring. The flaw alarm sensitivity was adjusted so that the C-scan would barely image notch 6, which presented the smallest area of the six notches. The actual depth of notch 6, as machined, was only .020 in. and not .047 in., as depicted in Figure 7. This accounts for the C-scan indication being so much smaller for notch 6 than for notch 3.

Figure 9 shows the correlation between the transducer position and the C-scan. Note that the threaded regions are imaged in addition to the bolt hole in the center of each threaded region. Note also that the "view" of the aft weld sidewalls is partially blocked in the threaded region. The three scans at the bottom of Figure 9 have been reduced to present the total scan. The difference between a good and a bad weld is quite clear. Also presented is the scan as it appears after proper test calibration. The dark regions at the top and bottom of each scan are reflections from the area underneath the weld root. These darkened areas form a convenient reference, marking the beginning and the end of each scan.

Estimation of defect size is made by comparing the defect indications on the C-scan with those made by the various size defects in the reference standard.

DESTRUCTIVE TEST CORRELATION

The validity of a nondestructive test technique is often best proven through destructive testing. Such destructive tests were used to verify both the forward and the aft weld techniques.

In the case of the forward weld, destructive testing was used to establish test sensitivity, as well as to measure the test accuracy. As mentioned previously, the C-scan printing threshold was adjusted to 25 percent of the reflection amplitude from the inside diameter of the forward weld turntable adapter. The sensitivity setting was determined empirically by scanning three warheads over a wide range of sensitivities. The warheads were then sectioned and the welds pulled apart. Figures 10, 11, and 12 show portions of the C-scan results at different sensitivities next to the actual weld root interface. The light area between the weld shoulder position line and the black unfused region represents good weld material. The best match was achieved at a sensitivity of 25 percent with an accuracy of $\pm .010$ in.

Only slight distortion of the weld occurred during destructive testing for most of the weld sections. Certain sections, however, could not be torn apart without severe distortion or failure of the parent metal. These sections generally occurred where the fused area was large and the weld was strong.

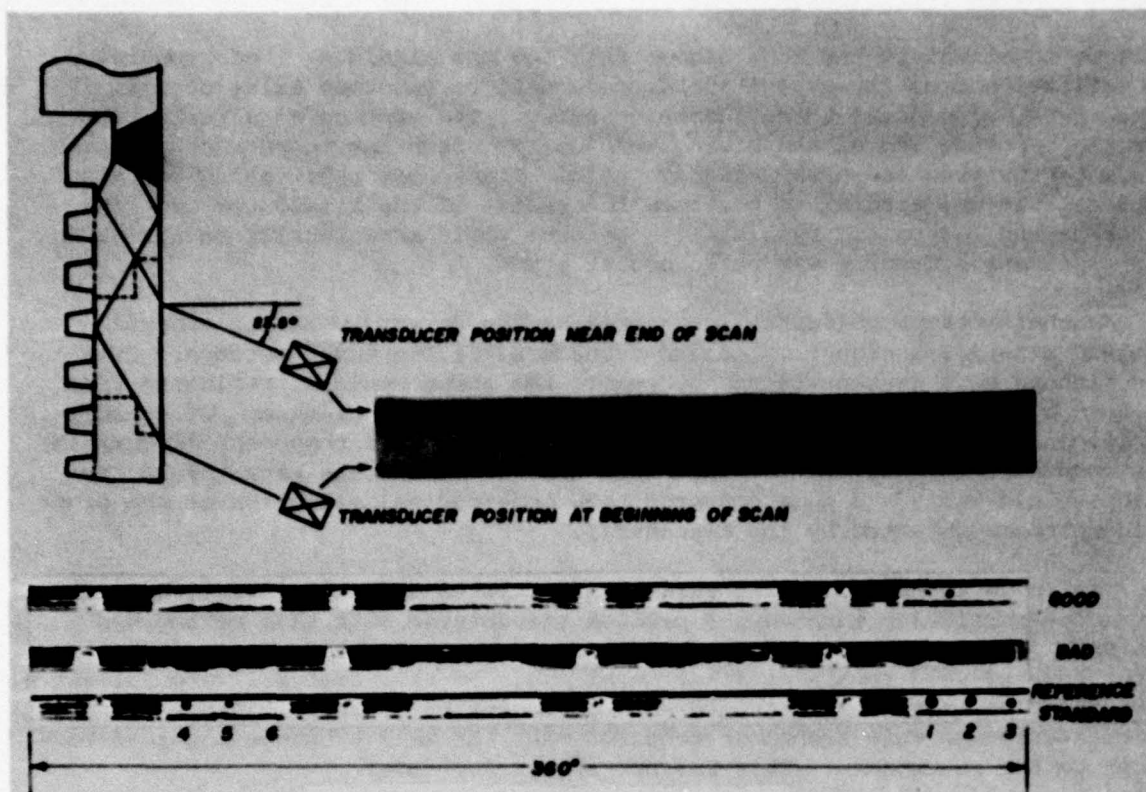


Figure 9. Aft Weld Inspection Technique

Correlation on the aft weld C-scan was also achieved through sectioning. The warhead, whose aft scan appears in Figure 9 as a "bad" example, was sectioned. The C-scan indicated that at least one of the aft weld sidewalls was nearly totally defective. Destructive sectioning showed the forward sidewall to be properly fused; however, the aft sidewall was almost totally disbonded. In addition, two warheads with C-scan indications of total fusion were sectioned. In both cases, the welds were stronger than the parent material.

UNSUCCESSFUL ATTEMPTS

Other ultrasonic test techniques were investigated, in addition to those previously reported. These techniques were either totally unsuccessful or they had severely limited applicability. The results are presented here, nonetheless, to avoid repetition by others, as well as to enhance the likelihood they may find applicability elsewhere.

One such attempt involved transmitting ultrasound down the entire length of the warhead casing. Lack of fusion in either the forward or aft weld side-

walls would attenuate the echo signal from the opposite end. Unfortunately, the reflection from the opposite end could only be detected using contact transducers, as opposed to an immersion setup. The absence of a reflection from the opposite end of the casing was just as often due to poor coupling as it was to the presence of a defective weld. Transducer positioning was also critical. It was crucial to position the center of the transducer over the center of the sidewall. Even still, the echo would occasionally be absent on good specimens. Testing was performed at 1 MHz.

Another attempt to further characterize the forward weld aft sidewall involved a normal incident immersion transducer at the outer surface. If a weld disbond were present in the sidewall, the sound would be reflected from the 60-deg sidewall at an angle equal to the angle of incidence. Of greater significance is the reflection at 30 deg of a shear wave component (Figure 13). This component strikes the machined weld shoulder, reflects back toward the defective sidewall, and mode converts to a longitudinal vibration at the proper angle to be detected by the transducer.

The above technique worked well with simulated defects of varying severity in one particular warhead. A problem encountered with this method was that some of the warheads had a significant portion of the forward sidewall of the forward weld remaining after machining. If this sidewall were defective, lack of fusion in the opposite sidewall could not be detected. Also, successful implementation of this technique required that the weld crown be machined back almost to the outer skin. This was not always the case.

DISCUSSION OF RESULTS

Sixty-four warheads were tested using the forward and aft weld immersion ultrasonic C-scan techniques. The results appear in the appendix of this report. The conditions of both welds varied from near zero to 100-percent fusion. These C-scans provided a means of selecting warheads for bend testing, determining the mechanical loading point most likely to cause failure, and measuring the pretest condition of the welds. The overwhelming majority of the warheads tested revealed little or no fusion of the forward weld root. In such instances, the load experienced by the warhead would be carried entirely by the weld sidewalls.

The C-scan technique may also have applicability beyond the rather limited scope of pre-bend-test weld characterization. It may also be of use in accepting new production warheads, in addition to reinspecting old production. An advantage of the C-scan technique over other previously used techniques is that it is not dependent on preconceived rejection criteria. The inspection does not simply call a weld section good or bad, but it can indicate how good or how bad. This feature would enable rejection criteria to be modified in the future, without the tremendous task of subsequent reinspection(s).

One should be cautioned that the ultrasonic techniques discussed in this report all suffer from a common limitation. These techniques cannot account for material property fluctuations in the weld and parent material. Such material properties certainly affect weld strength. This report has demonstrated that a good correlation can be made between ultrasonic test results and cross-sectional area of weld fusion. Assuming that material property fluctuations are small, one can then use the ultrasonic C-scan as an indicator of weld strength.

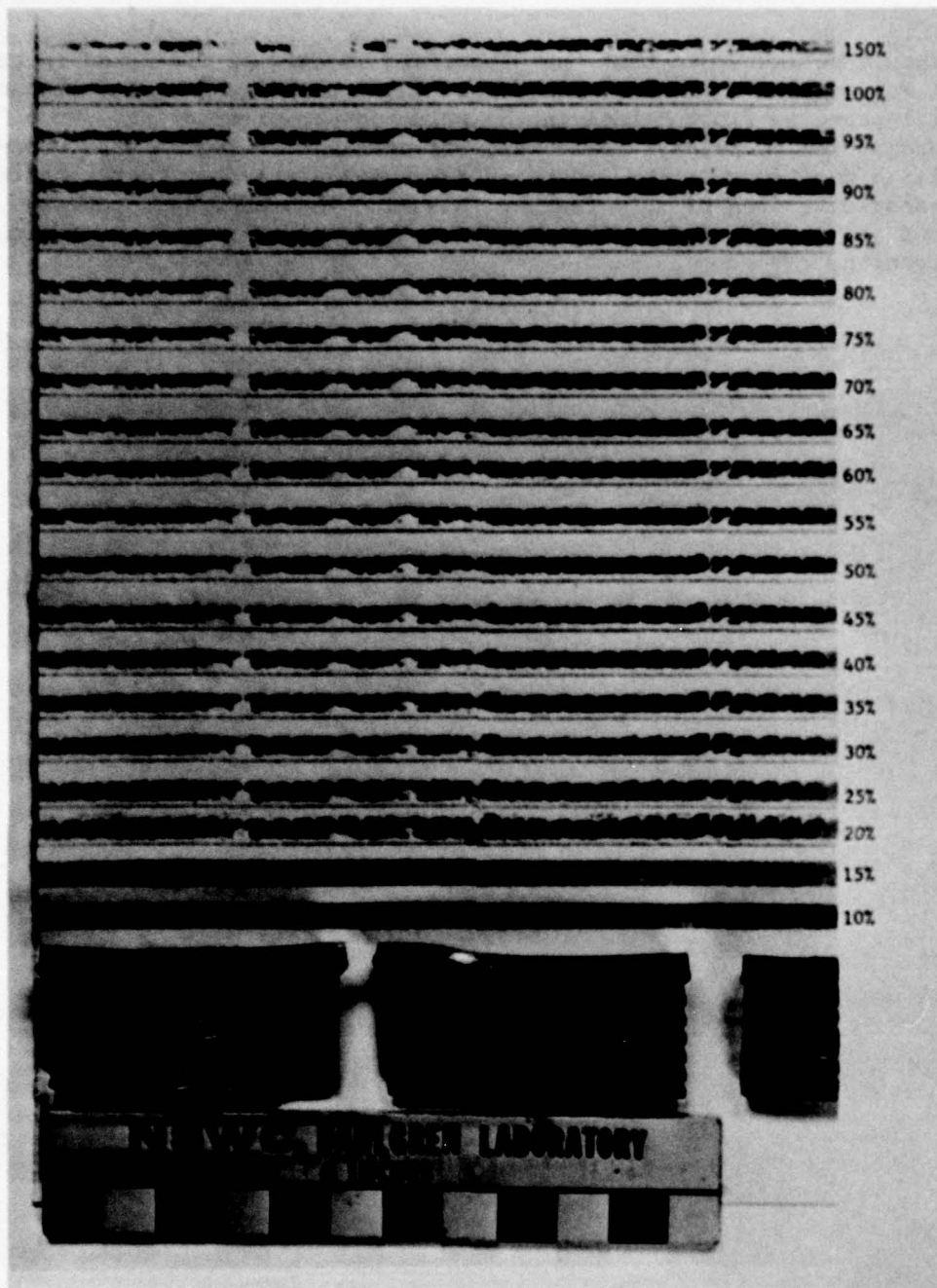


Figure 10. Correlation Between Destructive and
Nondestructive Testing (Items 1, 2, and 3)

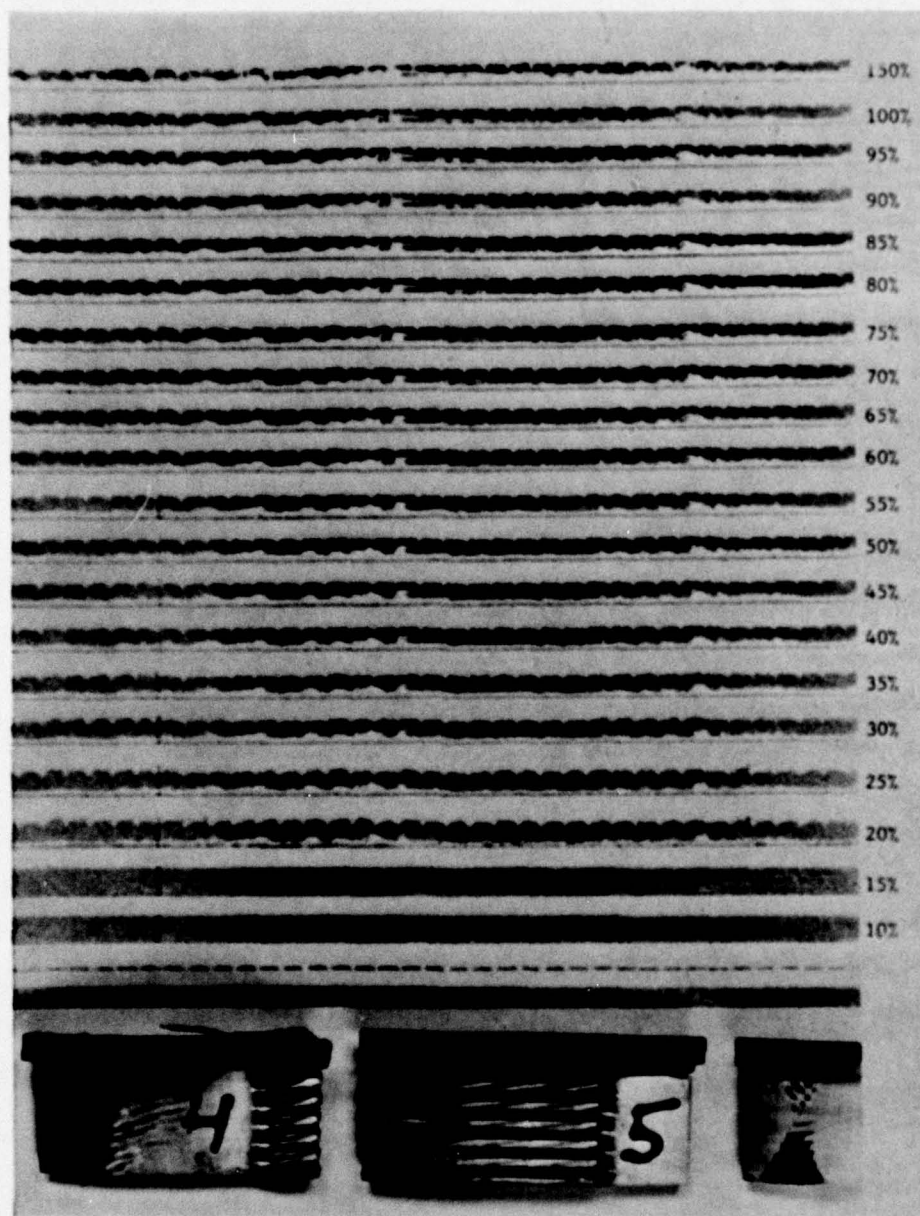


Figure 11. Correlation Between Nondestructive and Destructive Testing (Items 4 and 5)

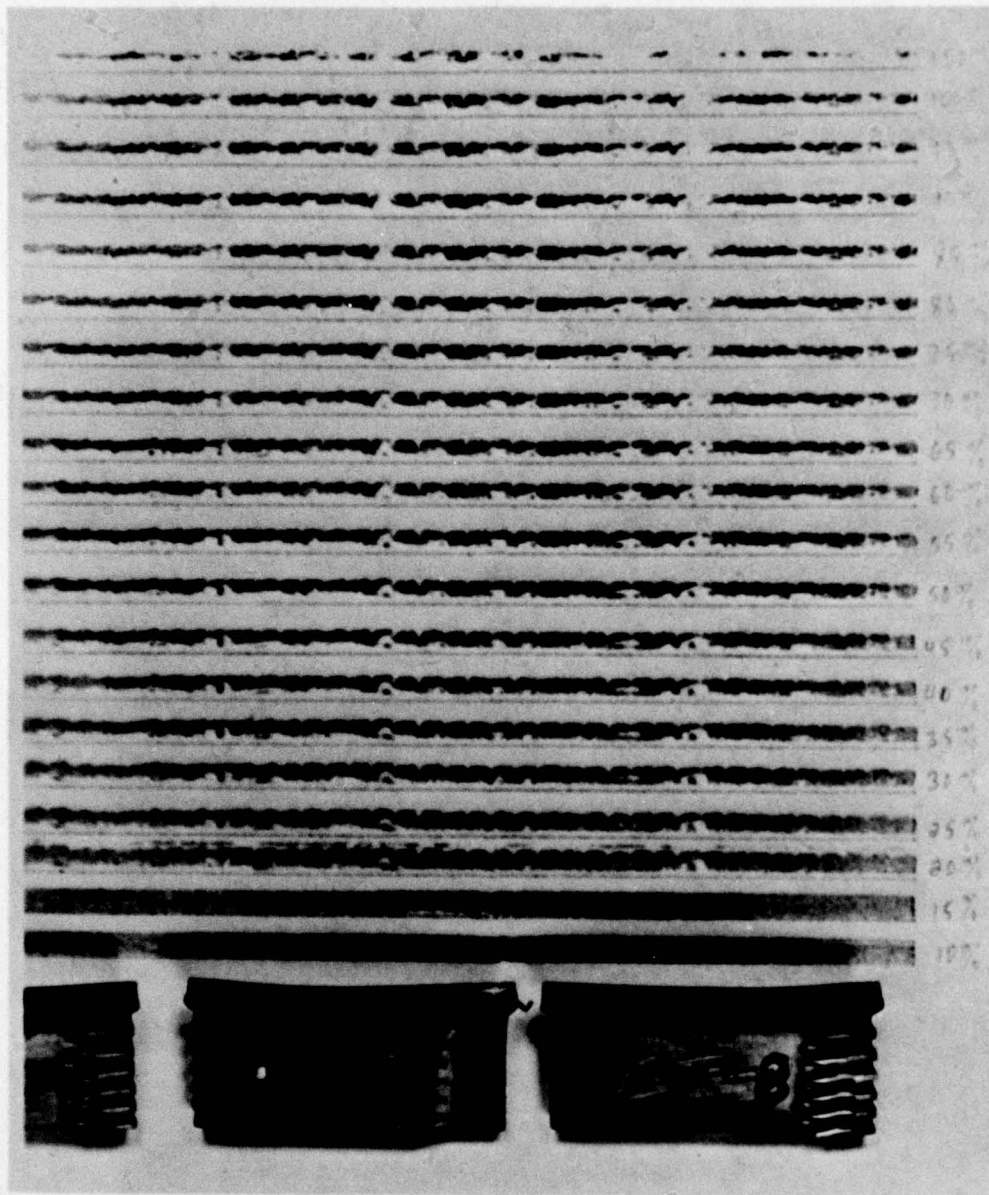


Figure 12. Correlation Between Nondestructive and Destructive Testing (Items 6, 7, and 8)

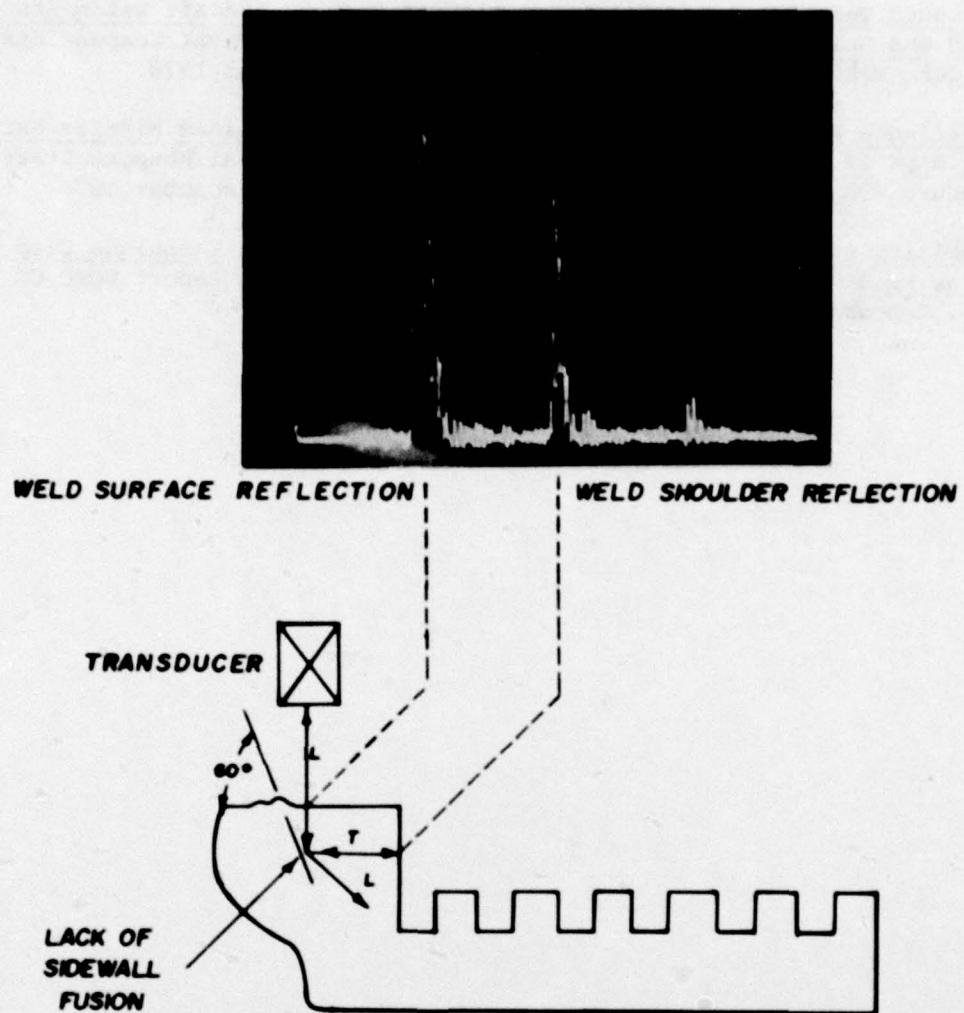


Figure 13. Forward Weld Aft Sidewall Inspection

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APPENDIX

FORWARD AND AFT WELD C-SCANS
FOR 64 WARHEADS

FWD

12407
14961
14381
3913
11501
GWE 358
GWE 412
GWE 422
MOW 119
14397

AFT

12407
14961
14381
3913
11501
GWE 358
GWE 412
GWE 422
14397
MOW 119

FWD

15412
 GWE 108
 15041
 14305
 GWE 273
 GWE 092
 DKU 0715
 14317
 13168
 GWE 382

AFT

15401
 15412
 GWE 108
 14305
 GWE 273
 GWE 092
 DKU 0715
 14317
 13168
 GWE 382

FWD

14299
 DKU 0764
 DKU 0638
 GWE 416
 DKU 0661
 14
 GWE 111
 GWE 369
 GWE 380
 DKU 0506

AFT

14299
 DKU 0764
 DKU 0638
 GWE 416
 DKU 0661
 14
 GWE 111
 GWE 369
 DKU 0506
 GWE 380

FWD

15509
14374
DKU 0613
MGW 096
13089
14385
QWE 075
12471
15582
10520

AFT

15504
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MGW 096
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QWE 075
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FWD

HGW 106
GWE 148
DKU 0773
12577
GWE 247
DKU 0657
14396
14333
GWE 431
14232

AFT

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DKU 0773
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14333
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GWE 433

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GWE 433

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DKU 0660

14324

GWE 370

AFT

GWE 340

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